Onboard Radar Processing Development for Rapid Response Applications

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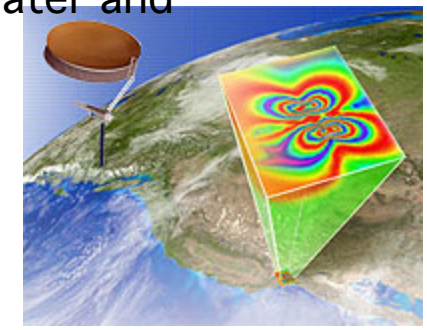
Outline

- Instruments DESDynI, UAVSAR
- Real-time On Board Processor (OBP)
- Modeling of OBP
- Applications
  - Low Latency Applications
    - Timeliness supersedes precision/fidelity
    - Easily interpreted – targeted data products

Background – DESDynI

- Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI)
  - Wealth of science data for: earthquakes, volcanic eruptions, landslides, ice-sheet and sea level changes in relation to climate change, land use and carbon budget changes, groundwater and hydrocarbon fluid migrations, species habitat changes…
- L-Band (1.2 GHz) InSAR, full polarimetric
- ~10m pixels over swaths 240km in range
- ~600km sun-synchronous orbit – 12-16 day period
- Sensor data production: 200 Mbps – 2000 Mbps
  - TDRRS: ~300 Mbps (Single access)



Background – UAVSAR + RealTime Processor

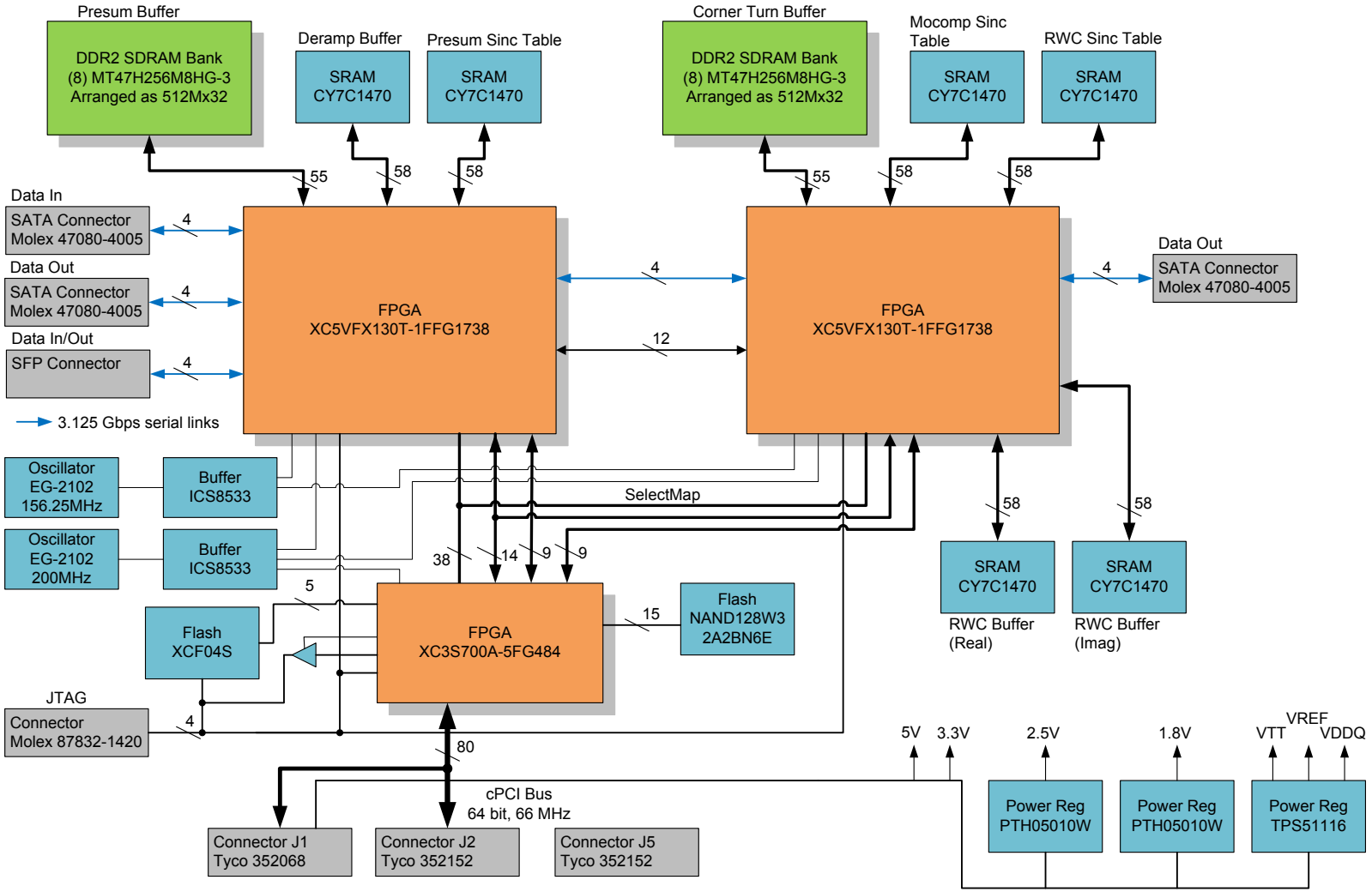
- Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)
- Airborne Radar, electronically steered, L-band
- ~2m resolution, typically multilooked to ~10m
- physical delivery of raw data
  - Iridium based downlink for real-time

- FPGA based real-time image formation
  - Geo-rectified polarimetric backscatter data products
  - Superficially: only improve latency between acquisition and delivery
    - Onboard processing may enable data-acquisitions that would not fit nominally with restricted downlink

OBP Summary

- Realtime onboard processing is performed with a hybrid system, a combination of a commercial microprocessor board, and custom designed FPGA boards (one FPGA board for each channel)
- The system is doing fully focused range / doppler processing, including range compression, presum, motion compensation, range walk correction and azimuth compression
  - For UAVSAR, input data is ~11M real samples/sec per channel
- A custom board with 2 Virtex5 FPGAs is used to perform all calculations that need to be performed on every data point
- All other calculations are performed in software on the commercial microprocessor board, with results passed to the FPGA board
  - Software is receiving radar headers, including accurate realtime information on platform attitude and position, and uses this to determine radar processing parameters to be passed to the FPGA board
  - The FPGA board buffers slightly more than one patch worth of data, to allow time for the microprocessor to determine the processing parameters to be used

OBP Board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(8) MT47H256M8HG-3
Arranged as 512Mx32
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SRAM
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58
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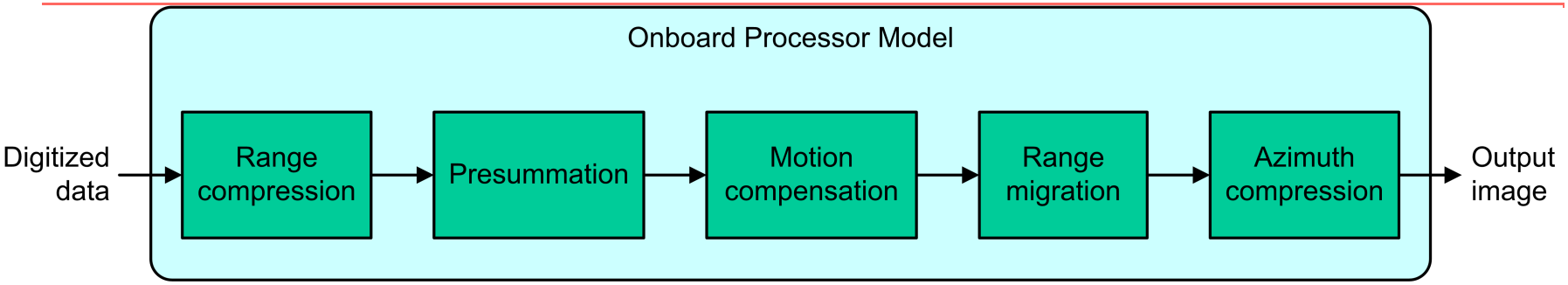
58
Data In
SATA Connector
Molex 47080-4005
Data Out
SATA Connector
Molex 47080-4005
Data In/Out
SFP Connector
4
4
4
FPGA
XC5VFX130T-1FFG1738
4
12
FPGA
XC5VFX130T-1FFG1738
4
Data Out
SATA Connector
Molex 47080-4005
3.125 Gbps serial links
Oscillator
EG-2102
156.25MHz
Buffer
ICS8533
Oscillator
EG-2102
200MHz
Buffer
ICS8533
SelectMap
58
58
SRAM
CY7C1470
SRAM
CY7C1470
RWC Buffer
(Real)
RWC Buffer
(Imag)
38
14
9
9
5
Flash
XCF04S
FPGA
XC3S700A-5FG484
15
Flash
NAND128W3
2A2BN6E
JTAG
Connector
Molex 87832-1420
4
80
5V
3.3V
2.5V
1.8V
VREF
VTT
VDDQ
cPCI Bus
64 bit, 66 MHz
Power Reg
PTH05010W
Power Reg
PTH05010W
Power Reg
TPS51116
Connector J1
Tyco 352068
Connector J2
Tyco 352152
Connector J5
Tyco 352152

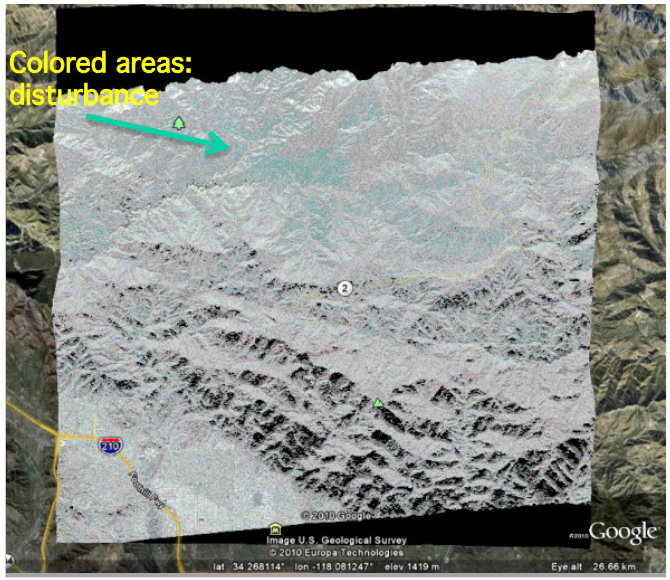
OBP Fixed-Point Modeling

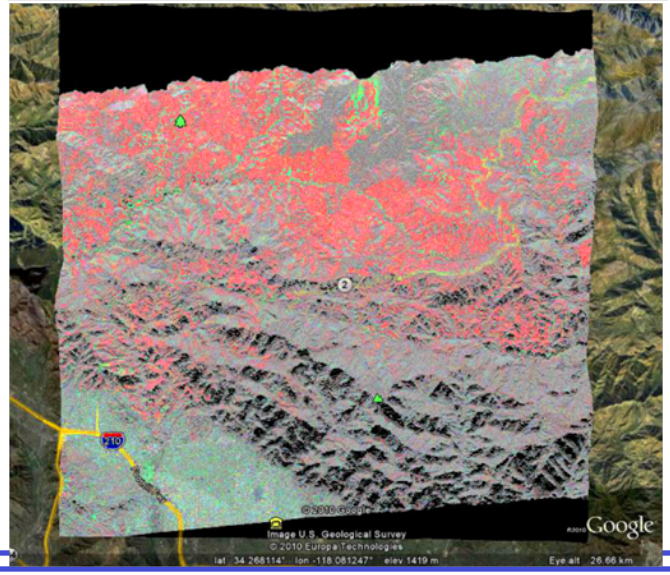


- To quickly prototype and evaluate OBP implementations, we have developed a fixed-point OBP model in Matlab.
  - OBP model is **modularized** and **parameterized** for easy reconfigurability
  - Each module can be run in two modes:
    - **Statistical floating-point** mode to measure node statistics for scaling purposes
    - **Bit-true fixed-point** mode to emulate hardware implementation

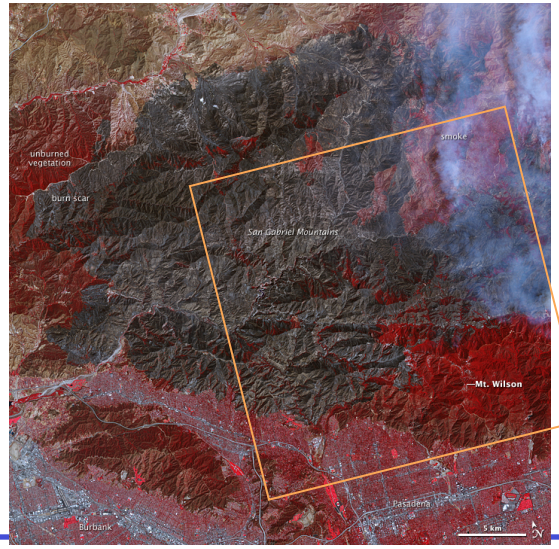
- OBP model uses our **custom fixed-point library**
  - Leverages **fast** interpreted operations in Matlab but remains **bit true**
    - Matlab Fixed-point Toolbox proved too slow given our large datasets
  - Includes libraries for complex arithmetic, relational operators, requantization, trigonometry (CORDIC), square roots (Newton-Raphson, nonlinear IIR, etc.), FFT/iFFT, among others
  - Runs in interpreted Matlab → fast, flexible algorithm development

Repeat Pass Disturbance





-Simple store-and-compare – requires significant storage for previous backscatter images
-Generic across domains: Fire monitoring, soil-moisture/flooding, landslide, urban disaster
-Requires interpretation



Three images of Angeles Forest, covering the 650km^2 Station fire. Top: UAVSAR HH backscatter, pre-fire colored blue, post-fire red. Bottom left: -3db change threshold, red for previously vegetated, green otherwise. Bottom-right: ASTER NIR image, highlighting burn scar. Approximate SAR registration indicated in orange.

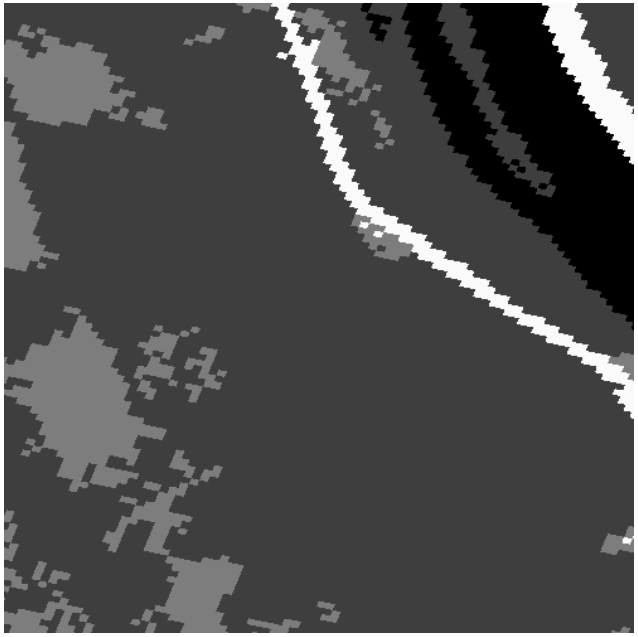
Vegetation Classification

- Coarse vegetation classes: none, low, med, high densities and open-water
- Can serve as proxy data for repeat pass disturbance (fire scar).
- Low bandwidth, direct use product, e.g. blowdown assessment.
- Support Vector Machine classification
  - U.S. National Land Cover Database 2001 serves as label repository (training and validation)
  - Features: full polarimetric backscatter channels, several ratios of backscatter, cross-pol phase difference

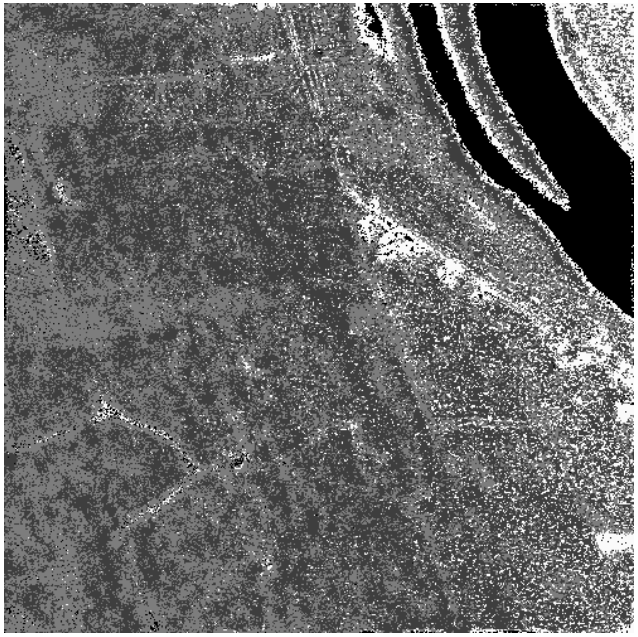
Vegetation Classification

- Cross validation against NLCD is poor – resolution and temporal disparity
- Qualitative comparison with more recent optical imagery is more compelling

NLCD2001 data condensed to none, low, med, high density vegetation and water classes (white, light – dark grey, and black respectively).



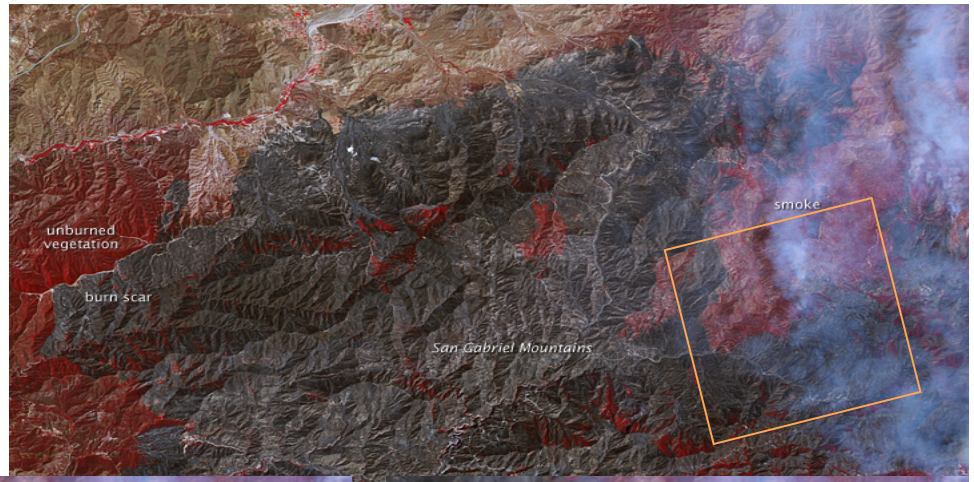
Trained SVM classification results on 2kmx2km area in US Maine (same color scheme as left).

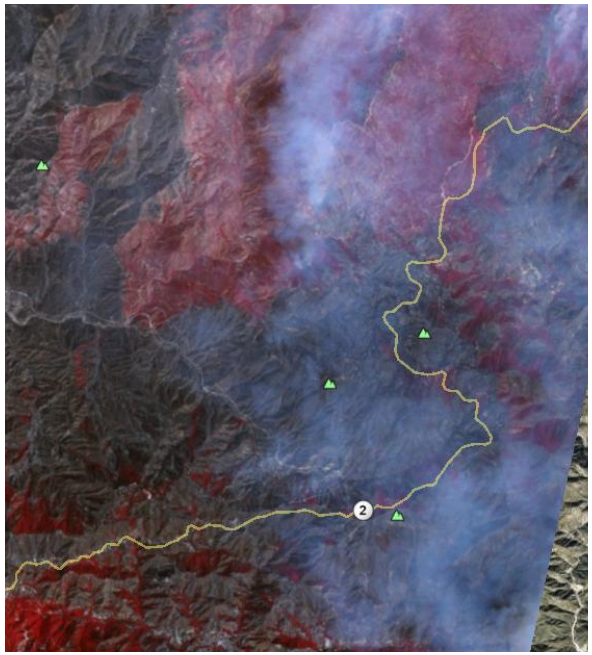


Optical image courtesy Google and Digital Globe (2009).

Vegetation Classification - Burn scar

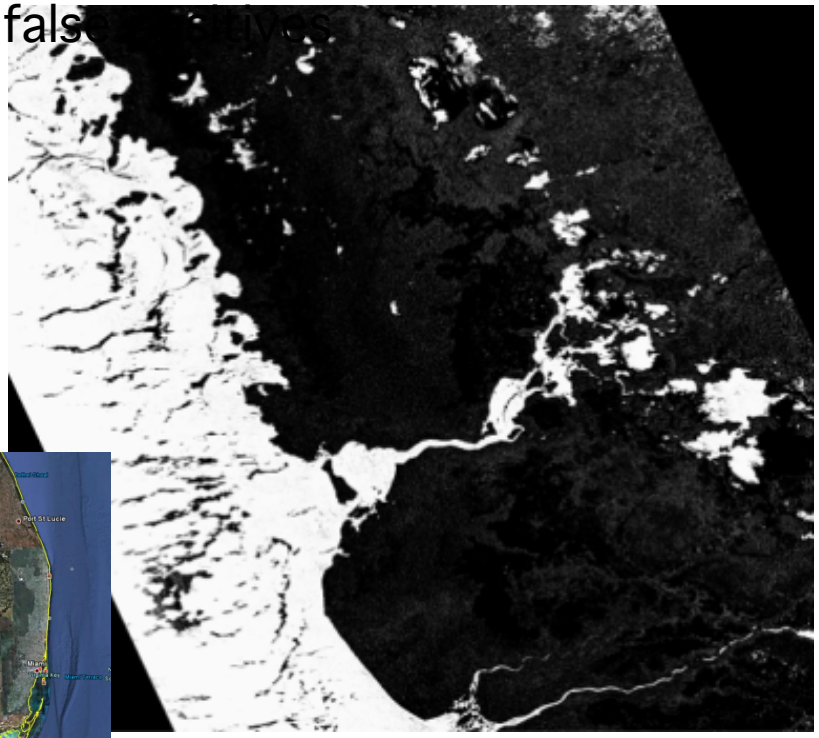
Classification of pre and post Station fire scar area.
White – bare land, darker – more vegetated.

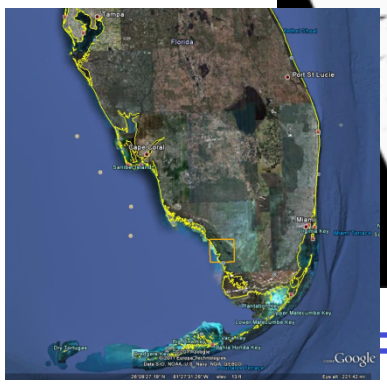




Surface Water Extent

- Use in flood response
- Dielectric estimation from backscatter HH and VV, and incidence angle
- Threshold > 15 – moist soil ~= 10, dry soil ~= 5, water ~= 80
- Surface roughness of water leads to false negative – smooth bare lands false positives





Florida Everglades
Detected water in white, land/other in black. Wind streaks on open water of Gulf of Mexico visible on left.

Snow and Ice

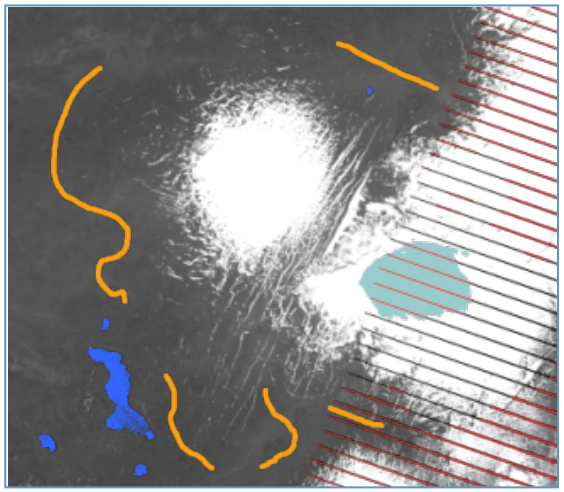
- Potentially used for ground transportation management, water use management,
- Another SVM classifier
- Train and validate on hand labels
  - Referencing optical imagery
    - Landsat 7 for iceland data, May 16 2009 (SAR: Jun 6, 2009)
    - EO-1 ALI for Sierra Nevada, January 10, 2011 (SAR: Jan 11, 2011)
  - Label: water, bare land, snow/ice
    - Train on ~1% of labels, cross validate on remaining

Snow and Ice

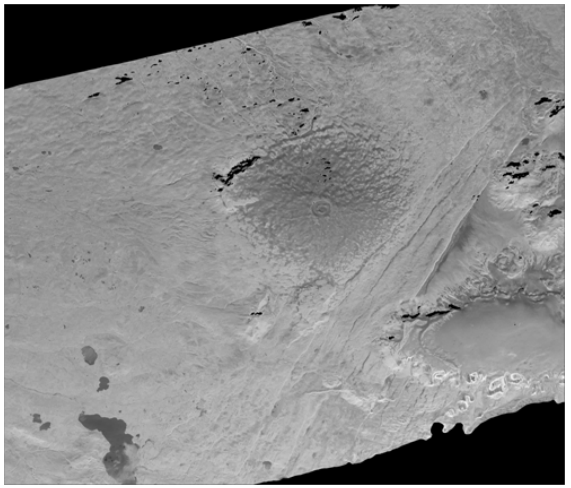
Iceland, Kaldidalur route, near Langjokull, Ok and Thorisjokull

Landsat 7 image, May (one month prior to SAR acquisition)

Overlaid are hand labels: blue-water, orange-bare land, teal-snow/ice, red-n/a

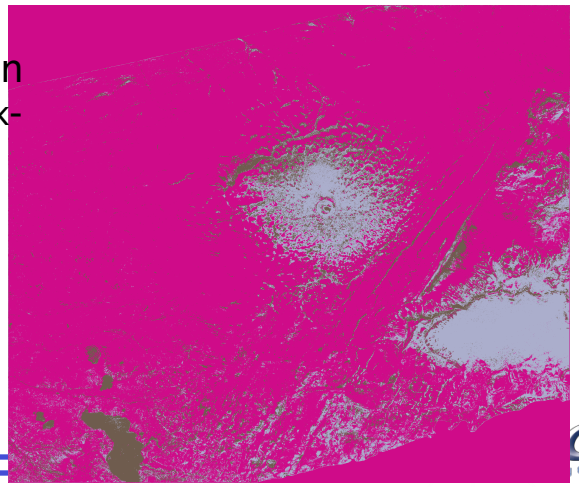


SAR backscatter image (HH)



Google Earth (CNES/Spot, Sept. 2002)

Classification output. pink-land, lt.grey-snow/ice, darkgrey-water.



Closing

- Data reduction through
  - SAR Image formation on board
  - classification maps
- Fire scar through change detection, both through full backscatter differences & classification map differences
- Surface water extent demonstrated
- Snow and Ice classification in un-vegetated areas

- Future
  - Improved ground truth for SVM training and cross-validation
  - Hardware accelerated evaluation (SVM)
  - Landslide application
  - Sea Ice Tracking